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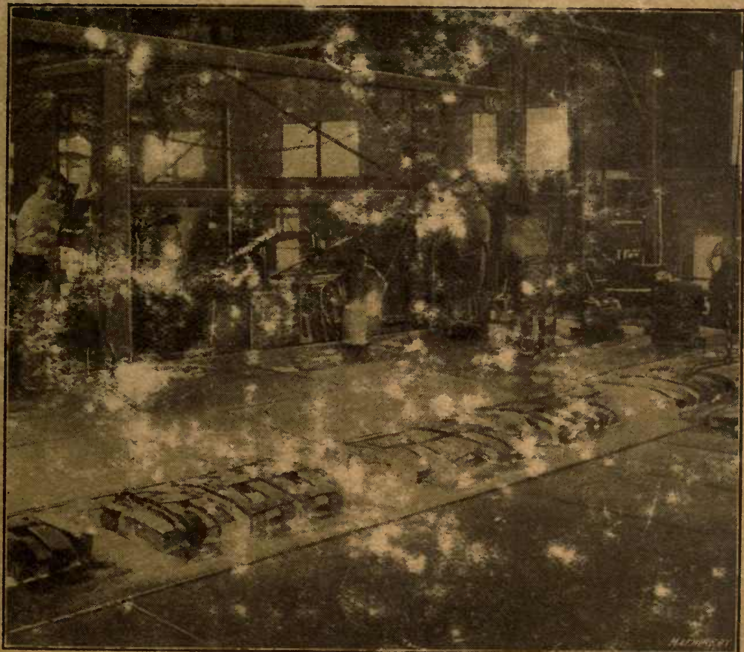
IRON AND STEEL

PRINCIPLES OF MANUFACTURE, STRUCTURE, COMPOSITION AND TREATMENT

THIRD REVISED EDITION



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NUMBER 36

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CHAPTER I

PRINCIPLES OF IRON AND STEEL MANUFACTURE*

The principles of iron and steel manufacture as outlined in the present chapter were originally given in an article by Mr. George Schuhmann in *The Pilot*, and republished in the August, 1907, issue of MACHINERY.

Commercial iron and steel are metallic mixtures, the chief ingredient of which is the element "iron," that is, pure iron, of which they contain from 93 per cent to over 99 per cent. The difference between iron and steel is principally due to the composition and proportion of the remaining ingredients.

Iron ore is an oxide of iron (iron rust) containing from 35 per cent to 65 per cent of iron; the balance is oxygen, phosphorus, sulphur, silica (sand), and other impurities. The ore is charged in a blast furnace, mixed with limestone as a flux, and melted down with either charcoal, coke, or anthracite coal as fuel; the resulting metal is what is commercially known as pig iron, containing about 93 per cent of pure iron, 3 to 5 per cent of carbon (pure coal), some silicon, phosphorus, sulphur, etc. This pig iron is used in foundries for the manufacture of iron castings, by simply remelting it in a cupola without materially changing its chemical composition; the only result is a closer grain and somewhat increased strength.

The Puddling Process

In the manufacture of wrought iron the pig iron is remelted in so-called puddling furnaces, by charging about ½ ton in a furnace; while in a molten state, the iron is stirred up with large iron hooks by the puddler and his helper, and kept boiling, so as to expose every part of the iron bath to the action of the flame in order to burn out the carbon. The other impurities will separate from the iron, forming the puddle cinder.

The purer the iron the higher is its melting point. Pig iron melts at about 2100 degrees F., steel at about 2500 degrees, and wrought iron at about 2800 degrees. The temperature in the puddling furnace is high enough to melt pig iron, but not high enough to keep wrought iron in a liquid state; therefore, as soon as the small particles of iron become purified they partly congeal ("come to nature"), forming a spongy mass in which small globules of iron are in a semi-plastic state, feebly cohering with fluid cinder filling the cavities between them. This sponge is divided by the puddler into lumps of about 200 pounds each; these lumps or balls are taken to a steam hammer or squeezer, where they are hammered or squeezed into elongated blocks (blooms), and while still hot, rolled out between the puddle rolls into

* MACHINERY, August, 1907.

bars 3 to 6 inches wide, ¾ inch thick, and 15 to 30 feet long. These bars are called puddle bars or muck bars, and, owing to the large amount of cinder still contained therein, they have rather rough surfaces. The muck bars are cut up into pieces from 2 to 4 inches long, and piled on top of each other in so-called "piles" varying from 100 to 2000 pounds, according to the size product desired. These piles are heated in heating furnaces, and when white hot, are taken to the rolls to be welded together and rolled out into merchant iron in the shape of either sheets, plates, bars, or structural shapes, as desired. When cold, this material is sheared and straightened, and is then ready for the market.

After leaving the puddling furnace, wrought iron does not undergo any material change in its chemical composition, and the only physical change is an expulsion of a large portion of the cinder; the small cinder-coated globules of iron are welded together and the subsequent rolling back and forth will elongate these globules, giving the iron a fibrous structure, and the reheating and rerolling will drive these fibers closer together, thus increasing the strength and ductility of the metal.

Classes and Kinds of Steel

The word steel, nowadays, covers a multitude of mixtures which are very different from each other in their chemical as well as physical qualities. The ingredient that exerts most influence on these variations is carbon. High grade razor steel contains about 1¼ per cent of carbon, springs 1 per cent, steel rails from ½ to ¾ per cent, and soft steel boiler plate may go as low as 1/16 per cent of carbon. Steel which is very low in carbon can easily be welded, but it cannot be tempered; when carbon is above 1/3 per cent, welding is more difficult and can only be done by the use of borax or some other flux, or by electric or thermit welding. Steel with carbon above ¾ per cent can be tempered, that is, when heated to red heat and then quenched in water or other liquid, it becomes very hard and can be used for tools of various kinds, such as saws, files, drills, chisels, cutlery, etc. In tool steel other ingredients are sometimes used to influence its hardness, such as nickel, manganese, chrome, tungsten, etc., the last named playing an important part in so-called "high-speed steels," that is, tool steels that will cut metal at a high speed without losing their temper or hardness.

As stated above, pig iron and cast iron contain about 4 per cent of carbon, and wrought iron only a trace of it, while steel is between these two extremes. The manufacture of steel, therefore, refers principally to getting the right proportion of carbon. One method is to take pig iron and burn the carbon out of it, as in the Bessemer and open-hearth processes, and the other method is to take wrought iron and add carbon to it, as in the cementation and crucible processes.

The Bessemer Process

In the Bessemer process the molten pig iron is put into a large pear-shaped vessel, called the converter, the bottom of which is double,

the inner one being perforated with numerous holes, called tuyeres, to admit air to be forced in under pressure. The molten iron (from 10 to 15 tons at a time) is poured into the converter while the latter is lying on its side; then the compressed air is turned into the double bottom as the converter rises to a vertical position. The air has sufficient pressure (about 20 pounds per square inch) to prevent the molten metal from entering the tuyeres. The air streams pass up through the molten metal (piercing it like so many needles), burning out the carbon, silicon, etc., accompanied by a brilliant display of sparks and a flame shooting out of the mouth of the converter. The 15 tons of molten pig iron contain nearly ¾ of a ton of carbon, and since this carbon is all burned out in less than ten minutes, this rapid rate of combustion increases the heat of the metal very much; it does not cool it, as one would suppose at first thought. The flame, therefore, at first red, becomes brighter and brighter, until it is finally so white that it can scarcely be looked at with the naked eye. A "blow" generally lasts about nine to ten minutes, when the sudden dropping of the flame gives notice that the carbon is all burned out. The metal in the converter is then practically liquid wrought iron; the converter is then laid on its side again, the blast shut off and a certain amount of spiegeleisen or ferromanganese is added in a liquid form so as to give the steel the proper amount of carbon and manganese to make it suitable for the purpose desired. The liquid steel is then poured out into so-called "ingot molds," and the resulting "ingots," while still hot, but no longer liquid, are rolled out into blooms, billets, or rails without any additional reheating except a short sojourn in so-called "soaking pits." In some steel works, where the molten pig iron is taken in large ladle cars direct from the blast furnace to the converter, it is possible to produce rails without adding any fuel to that contained in the molten pig iron, so that the red-hot rail just finished still contains some of the heat given it by the coke in the blast furnace.

The Open-hearth Process

The open-hearth process, sometimes called "the Siemens-Martin process" is similar to the puddling process, but on a much larger scale. The furnaces generally have a capacity of from 40 to 50 tons of molten metal (in some exceptional cases as high as 200 tons); they are heated by gas made from bituminous coal (oil and natural gas have also been used). The gas and the air needed for its combustion are heated to a high temperature (over 1000 degrees) before entering the combustion chamber, by passing through so-called regenerative chambers. Owing to this preheating of the gas and the air, a very high temperature can be maintained in the furnace, so as to keep the iron liquid even after it has parted with its carbon. The stirring up of the molten metal is not done by hooks as in the puddling furnace, but by adding to the charge a certain proportion of ore, iron scale, or other oxides, the chemical reaction of which keeps the molten iron in a state of agitation. While in the Bessemer process only pig iron is used, in the open-hearth furnace it is practicable to

use also scrap of wrought iron or steel, as the high temperature in the furnace will readily melt it. When the pig iron or scrap contains too much phosphorus, burnt lime is added to the charge; the resulting slag will absorb the phosphorus, thus taking it out of the metal. This dephosphorization by means of burnt lime is called the basic process in contradistinction to the acid process, where no lime is used, but where care must be taken that the metal charged is low in phosphorus. In this country, the basic process is at present used only in connection with open-hearth furnaces, while in Europe it is also used in many Bessemer plants producing the so-called "basic Bessemer steel."

Producing Tool Steel

Crucible steel or tool steel, formerly called cast steel, is made by using high grade, low phosphorus wrought iron and adding carbon to it by methods which will be described in detail in the next chapter. The oldest method is the "cementation process" in which iron bars were packed in air-tight retorts, with powdered charcoal between the bars. The filled retorts were put into a furnace, where they were heated to a red heat for several days. The carbonized bars, commonly called "blister steel," were then cut into small pieces, remelted in a crucible, and from there poured into molds, forming small billets. The newer method is to put the small pieces of wrought iron direct into an air-tight crucible mixed with the proper amount of powdered charcoal, and melt down. The other ingredients, such as chrome, tungsten, etc., are also added in the crucible.

Malleable and Steel Castings

Malleable castings are produced in the reverse way from the blister steel referred to above, that is, instead of taking wrought iron and adding carbon, castings made of cast iron are made malleable by extracting the carbon. The castings are packed into retorts similar to the cementation retorts, but, instead of charcoal, an oxide of iron, generally in the shape of hematite ore, is packed with them, and kept in a red-hot state for several days. The oxygen of the ore will absorb the carbon in the iron, giving the latter a steely nature.

Steel castings used to be produced in the same manner, but now, steel castings are cast direct from the ladle containing molten steel, which is generally melted in an open-hearth furnace, although small Bessemer converters are also sometimes used for this purpose.

Difference between Wrought Iron and Low Carbon Steel

While chemically there is not much difference between wrought iron and low carbon steel, there is considerable difference in their physical structures. Owing to the globules of pure iron being coated with cinder in the puddling furnace, the subsequent rolling and reworking, while expelling a large portion of this cinder, always leaves a trace of it behind which gives wrought iron the fiber. Steel having been produced in a liquid form, where the cinder all floated to the top and was removed, the metal is homogeneous, that is, without any grain or fiber. When subjected to many vibrations, or strains due to frequent

expansion and contraction, wrought iron will generally yield gradually and give warning to the inspector, while steel is more liable to snap off suddenly. Wrought iron being composed of many fibers, the fibers can break one at a time without directly affecting its neighbor (like the strings in a rope), while a rupture once started in steel will extend more rapidly. Wrought iron will also resist corrosion and pitting longer than steel, no doubt due to the higher resisting power of the enclosed cinder, which also causes the acid to deflect endwise, thus weakening its action by diffusing it over a larger area and preventing deep pitting. Stay bolts and boiler tubes for locomotives have proved more satisfactory when made of wrought iron than of steel. Thin sheets, tin plate, corrugated iron covering, wire fencing, pipes, oil well casings, etc., have also proved much more durable when made of wrought iron than when made of steel. On the other hand, in rails, tires, guns, armor plate, etc., steel has proved far superior to iron, owing to its greater strength and hardness; corrosion is also here of minor importance, owing to the rails, etc., generally being worn out long before corrosion has a chance to affect them seriously. When structural steel or iron is used for bridges, etc., it is necessary to protect the metal from serious corrosion by frequent and careful painting; in the skeletons of high office buildings and other skyscrapers, when completely covered with concrete, etc., so as to thoroughly exclude air or moisture, steel as well as iron will last indefinitely.

Where material is buried in the ground, or exposed to the weather without the careful protection of paint, or where moisture has access to it by other channels, as in the interior of pipes, for instance, wrought iron will outlast steel by a good margin.

Graphical Illustration of the Metallurgy of Iron*

The diagram Fig. 1 illustrates graphically the metallurgy of iron from the mine to the market and affords an interesting means of tracing out the different processes and showing the kind of steel or iron which each process produces. What has been said in the previous part of this chapter is, in a way, summarized in this diagram. Thus we see that the ore may, by the direct process, be changed at once to wrought iron in which form it is placed upon the market. The ore may go direct to the blast furnace or, if volatile substances are contained in the ore, it is first roasted, by which method these substances are removed and the ore made ready for the blast furnace. In the blast furnace the ore is changed to pig iron of various grades which may be placed directly upon the market or it may be then treated by any one of several processes. If treated by the Bessemer process the pig iron is changed to ingot iron, in which form it is placed upon the market. If treated by the open-hearth process it is also changed to ingot iron. If, however, the pig iron is sent to the foundry it is made into cast iron and placed upon the market in the form of castings. In the puddling furnace the pig iron is changed to

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* MACHINERY, December, 1903.

marketable wrought iron or it may be treated by the cementation process, in which it is changed to blister steel, from which, by the crucible process, we obtain tool steel.

Uniform Nomenclature of Iron and Steel*

At the Brussels Congress of the International Association for Testing Materials held in September, 1906, a report was presented on "The Uniform Nomenclature of Iron and Steel." The following definitions of the most important forms of iron and steel are given:

Alloy cast irons: Irons which owe their properties chiefly to the presence of an element other than carbon.

Alloy steels: Steels which owe their properties chiefly to the presence of an element other than carbon.

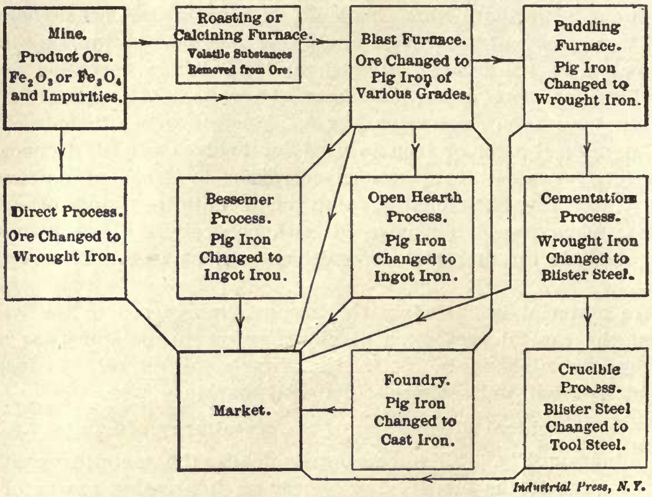

Fig. 1. Chart Illustrating the Metallurgy of Iron

Basic pig iron: Pig iron containing so little silicon and sulphur that is suited for easy conversion into steel by the basic open-hearth process (restricted to pig iron containing not more than 1.00 per cent of silicon).

Bessemer pig iron: Iron which contains so little phosphorus and sulphur that it can be used for conversion into steel by the original or acid Bessemer process (restricted to pig iron containing not more than 0.10 per cent of phosphorus).

Bessemer steel: Steel made by the Bessemer process, irrespective of carbon content.

Blister steel: Steel made by carburizing wrought iron by heating it in contact with carbonaceous matter.

Cast iron: Iron containing so much carbon or its equivalent that it is not malleable at any temperature. The committee recommends drawing the line between cast iron and steel at 2.20 per cent carbon.

* MACHINERY, December, 1906.

Cast steel: The same as crucible steel; obsolete, and confusing.

Converted steel: The same as blister steel.

Charcoal hearth cast iron: Cast iron which has had its silicon and usually its phosphorus removed in the charcoal hearth, but still contains so much carbon as to be distinctly cast iron.

Converted steel: The same as blister steel.

Crucible steel: Steel made by the crucible process, irrespective of carbon content.

Gray pig iron and gray cast iron: Pig iron and cast iron in the fracture of which the iron itself is nearly or quite concealed by graphite, so that the fracture has the gray color of graphite.

Malleable castings: Castings made from iron which when first made is in the condition of cast iron, and is made malleable by subsequent treatment without fusion.

Malleable iron: The same as wrought iron.

Malleable pig iron: An American trade name for the pig iron suitable for converting into malleable castings through the process of melting, treating when molten, casting in a brittle state, and then making malleable without remelting.

Open-hearth steel: Steel made by the open-hearth process irrespective of carbon content.

Pig iron: Cast iron which has been cast into pigs direct from the blast furnace.

Puddled iron: Wrought iron made by the puddling process.

Puddled steel: Steel made by the puddling process, and necessarily slag-bearing.

Refined cast iron: Cast iron which has had most of its silicon removed in the refinery furnace, but still contains so much carbon as to be distinctly cast iron.

Shear steel: Steel, usually in the form of bars, made from blister steel by shearing it into short lengths, piling, and welding these by rolling or hammering them at a welding heat. If this process of shearing, etc., is repeated, the product is called "double shear steel."

Steel: Iron which is malleable at least in some one range of temperature and in addition is either (*a*) cast into an initially malleable mass; or, (*b*) is capable of hardening greatly by sudden cooling; or, (*c*) is both so cast and so capable of hardening.

Steel castings: Unforged and unrolled castings made of Bessemer, open-hearth, crucible or any other steel.

Washed metal: Cast iron from which most of the silicon and phosphor have been removed by the Bell-Krupp process without removing much of the carbon, still contains enough carbon to be cast iron.

Weld iron: The same as wrought iron; obsolete and needless.

White pig iron and white cast iron: Pig iron and cast iron in the fracture of which little or no graphite is visible, so that their fracture is silvery and white.

Wrought iron: Slag-bearing, malleable iron, which does not harden materially when suddenly cooled.

CHAPTER II

THE MAKING OF TOOL STEEL*

Few mechanical processes have, during the general progress of engineering, undergone so little change as the methods and process employed in the making of tool steel. With the exception of a more direct method for introducing the carbon into the steel, it may be said that, in general, the same methods are still used as were employed centuries ago. Improved methods for heating the furnaces and for handling and working the steel at various stages of the manufacture have, of course, been introduced, but there has been no new principle applied in the actual production of the steel.

General Procedure in Making Tool Steel

Before describing in detail the various processes and operations involved in the making of tool steel, the general procedure may be briefly reviewed as follows: As mentioned in the previous chapter, tool steel is made by using low phosphorus and sulphur wrought iron and adding carbon to it. Two methods have been in use, the older one being the so-called cementation process, in which the wrought-iron bars were packed in air-tight retorts with powdered charcoal placed between the bars. When the retorts were thus filled, they were put into a furnace, called the cementation furnace, where they were heated to a red heat and permitted to remain at that temperature for several days. During this time the iron absorbed carbon from the charcoal up to about 1½ per cent of its own weight. The process, in fact, is similar to the ordinary case-hardening process for giving parts made of low-carbon machine steel a hard high-carbon surface. The carbonized bars, called "blister" steel, were then cut up into small pieces and were remelted in a crucible, and from that poured into molds. The billets thus formed were afterwards hammered or rolled into the desired shapes.

The newer method, exclusively employed at the present time, consists of putting small pieces of wrought iron directly into a crucible together with the proper amount of powdered charcoal. This charge is then melted and permitted to remain in the molten state for some time before being poured into molds. While in the molten state the iron will absorb the carbon much quicker than when only red hot, as in the cementation process. When the carbon is added directly in the crucible it is also possible to more accurately determine the carbon content of the final product and for this reason the newer method is far superior to the cementation process. The methods employed in the steel-making plant of the Heller Brothers Co. of Newark, N. J., are in accordance with the modern practice, and it is the object of the present chapter to briefly describe the making of tool steel as this process is carried on at these works.

* MACHINERY, November, 1909.

History of the Heller Brothers Company

The original business of which the present plant of the Heller Brothers Co. is an outgrowth was established in 1836 by Mr. Elias Heller, who at that time engaged in the making of files and horse rasps. Up to that time English files had been used exclusively in the United States, and Mr. Heller was one of the first, if not the very first man, to make files in this country. The business gradually grew until the first buildings of the present factory were erected in 1873 at Forest Hill, a suburb of Newark.

It was found that a relatively low-carbon steel of a uniform composition, such as is required in the manufacture of horse rasps was impossible to obtain at that time in the United States at a reasonable price, and, for this reason, in 1881, the firm built a small plant for the manufacture of high-grade tool steel primarily for its own use. Since then, however, this department of the plant has been considerably increased so that at the present time the firm manufactures a considerable quantity of steel for the market, specializing particularly in high-grade brands of carbon tool steel and high-speed alloy steels. The plant now includes a melting furnace having a capacity of thirty crucibles at a time, a number of steam hammers and a small rolling mill, besides the required heating and annealing furnaces.

Material Used for Making Tool Steel

The raw material used by the Heller Brothers Co. for the making of tool steel is Swedish (Dannemora) wrought iron having a carbon content of from 0.10 to 0.20 per cent. This iron comes in flat bars, ½ by 2 inches, and is cut up into small pieces about one inch wide. The reason why Swedish iron is used in preference to other kinds is that it has proved itself superior in the making of high-grade tool steels. It is possible to obtain American iron having by chemical analysis practically the same composition as the Dannemora iron, and being as free from phosphorus, but nevertheless, when transformed into tool steel, the final product will not be of the same quality as that made from the Swedish iron. Metallurgists are at a loss to explain the reason for this. Steel makers say that the Swedish iron has more "body," but, of course, this in itself does not mean anything except that it produces better results. One cause may be that the Swedish iron ore originally contains less impurities, and that for this reason wrought iron of a given quality can be produced without having passed through, in the same degree, the processes necessary for removing the impurities from the iron ore. These processes possibly change somewhat the crystalline structure of the iron, although its chemical composition remains exactly the same. This is mere theory, however, and should not be accepted as the demonstrated cause of the superiority of the Swedish wrought iron for the making of tool steel.

The Melting Furnace

The furnace in which the crucibles containing the metal are heated, which, as already mentioned, has a capacity of thirty crucibles at a

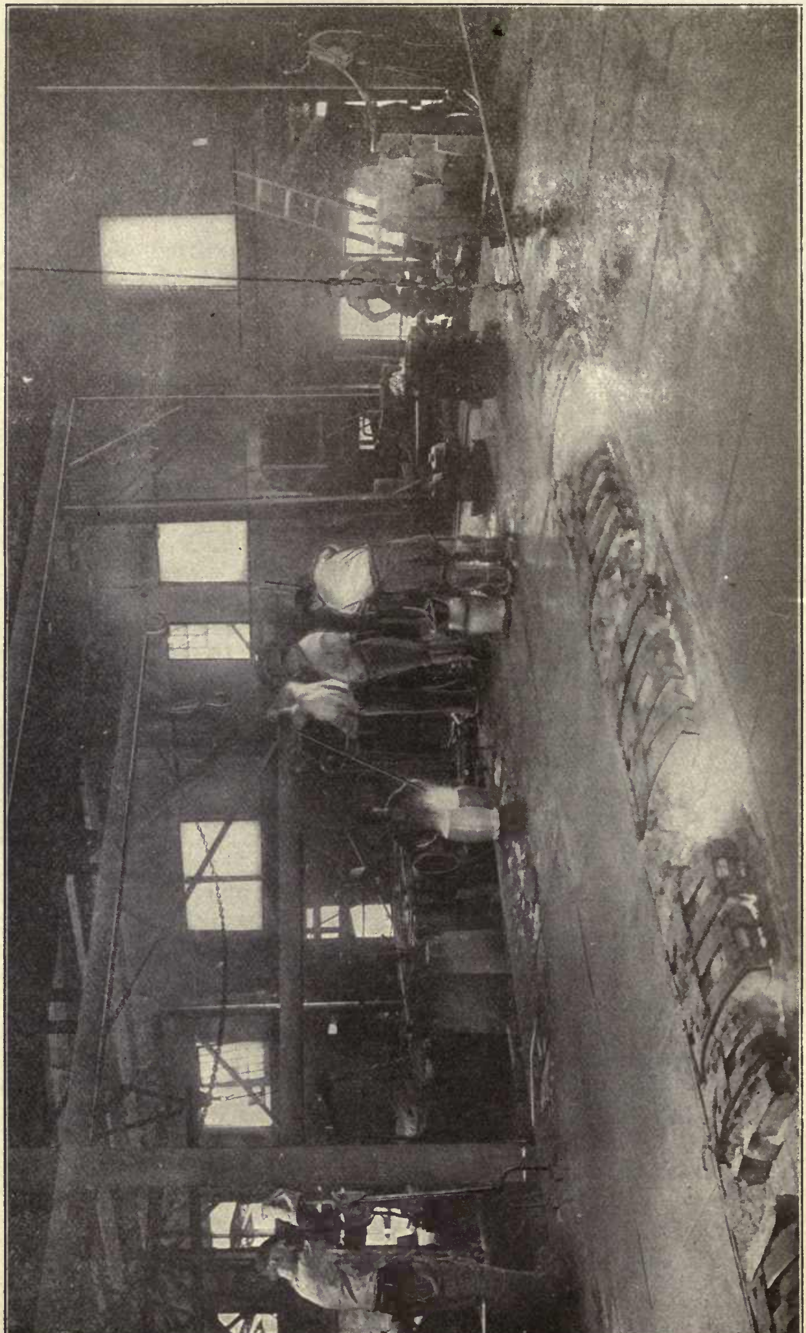

Fig. 2. Tool Steel Furnace and Charging Floor at the Heller Brothers Company's Plant, Newark, N. J.

time, is gas heated, the gas being obtained from a gas producer in the company's plant. The furnace is of the Siemens type, the gas entering it alternately from either side through checker plates. The action of the furnace is as follows: When the gas enters on one side, the exhaust gases pass out through the checker plates on the other side; these exhaust gases, being of a very high temperature, heat the checker plates rapidly to a red heat; at this time the entering gas is automatically shut off, and gas is admitted from the opposite side. This gas, then, passing through the heated checker plates, is thoroughly preheated, and when combustion takes place a much higher degree of total heat is obtained. The combustion gases from this side now heat the checker plates on the other side, and the process of pre-heating the gas as it enters alternately from the two sides of the furnace is thus automatically taken care of.

The charging floor, or the floor on which the men work who insert the crucibles in and remove them from the furnace, is level with the top of the furnace, and iron-braced fire-brick covers, as shown in Fig. 2, are provided, which are kept over the openings of the furnace at all times except when a crucible is put in place or removed. The furnace, of course, is built up of fire brick, and is covered on top with steel plates. It is kept running continuously day and night, as it would crack and be destroyed by the severe internal stresses due to sudden cooling if the fire were permitted to go out. The life of the furnace is from six months to a year, after which time it must be rebuilt.

Crucibles

One of the crucibles used for the melting of the iron is shown in Fig. 3. The height of the crucible is about 20 inches and it is one foot in diameter at the central part. When placed in the furnace it is provided with a fire-clay cover not shown in the illustration. The crucible has a capacity of seventy-five to eighty pounds of iron. It is made from a mixture consisting of several foreign and domestic clays of proper proportions. The crucibles are manufactured in the plant of the company, and are made in a manner similar to that used for making clay pots. A form is used to give the outside shape, and a revolving former is employed to shape the inside. When the crucible has been thus formed it is permitted to dry at ordinary room temperature, a storage room being provided where the crucibles are lined up on shelves for the purpose of drying. When properly dried, they are put into an annealing furnace where they are slowly heated to a high temperature. They must then be taken directly from the annealing furnace while hot, charged with the iron and charcoal, and put into the melting furnace. After this the clay crucible is not permitted to cool off until its usefulness is past. The heat of the crucible and the charge while in the furnace is from 2500 to 2800 degrees F.

Comparison between Clay and Graphite Crucibles

The use of clay crucibles in preference to crucibles of graphite is important in the making of high-grade tool steel, and is in accordance

with the practice employed by the best English steel makers at Sheffield, where the clay crucible has been used for this purpose for centuries past. When the clay crucible is used, there is absolutely no possibility of any extraneous matter mixing with the charge, and the carbon content can be very closely predetermined. When a graphite crucible is used, small particles of graphite will flake off from the inside of the crucible and these particles will mix with the charge. They will, however, not enter into chemical composition with the steel, but will merely mix with it mechanically, so that, in the steel, there will be small particles of graphite imbedded, thus producing small holes and flaws in the finished material. The graphite crucible, however, will last longer, and is therefore cheaper to use, but when a high-grade tool

Fig. 3. The Charge of Swedish Iron, Bag of Charcoal, and the Clay Crucible in which the Charge is melted

steel is to be produced the clay crucible is the only one which will give entirely satisfactory results.

Melting and Pouring the Steel

The work of charging or filling the crucibles and pouring the molten metal into the molds is carried out on the charging floor, shown in Fig. 2. The crucibles are charged with about seventy-five pounds of wrought iron cut up into pieces, as has already been mentioned, a pile of wrought iron ready for the crucible being shown in Fig. 3. About half of the iron is first put into the crucible, then a bag containing the powdered hardwood charcoal, shown on the top of the pile of iron pieces in Fig. 3, is put in, and finally the remainder of the iron charge is placed on top of this. When high-speed steel is made, other ingredients, such as chromium, tungsten, molybdenum, etc., are placed in the crucible together with the charcoal and iron.

The carbon content in the tool steel is determined by the amount of

charcoal in the charge; some carbon, of course, is contained in the wrought iron, so that it is not possible to calculate directly the proportions of charcoal necessary for a certain weight of iron to produce a given percentage. Some of the charcoal is also lost in the slag. The common method of determining the amount of charcoal required, however, is to consider that each ounce of charcoal will give about 0.07 per cent carbon to the steel, or, as the steel maker would express it, one ounce charcoal gives seven "points" carbon. This proportion is approximately correct for ordinary carbon contents, but when steel of a high carbon content is required it is necessary to add charcoal in a greater proportion, partly on account of the fact that the original amount of carbon in the wrought iron is then of relatively less im-

Fig. 4. Pouring the Molten Steel. The Photographic Plate shows the Intense Light and Heat and Fire-works Effect

portance, and partly because more of the carbon is lost or wasted. The charge for high-speed steel of standard quality is proportioned so as to give 5 to 6 per cent chromium, 19 to 20 per cent tungsten, and 0.55 to 0.75 per cent carbon.

The crucibles are placed into and lifted up out of the furnace by means of large tongs, the men doing the work standing partly over the furnace while removing the crucible. In Fig. 1 a crucible had just been removed from the furnace from where it was immediately moved across the floor to the molds, which stand vertically, and into which the molten metal is poured to form the ingot. Before pouring, however, but after the crucible has been removed from the furnace, the slag collecting on the surface of the metal is first removed by a long iron bar, and then a small amount of manganese is put into the crucible. This prevents the oxidizing of the metal while being poured, and tends to insure freedom from blow holes or flaws in the ingots. A number of molds ready to have the metal poured into them are shown in Fig. 5, the photograph

being taken from the level of the floor of the shop, which is several feet below the level of the charging floor. One of the molds which are made in halves, is shown opened up in this illustration. The molds are made of cast iron and the standard inside dimensions of the molds, and, of course, also the dimensions of the ingots, are four inches square, by about three feet long, the ingots containing about 150 pounds of iron, or the contents of two crucibles with a capacity of seventy-five pounds each. In Fig. 2, one crucible has just been poured into the mold and is now being recharged, while the other crucible stands on the side of the mold ready to be poured. Fig. 4 is a photograph taken at the moment of pouring the molten metal into the mold. The intense

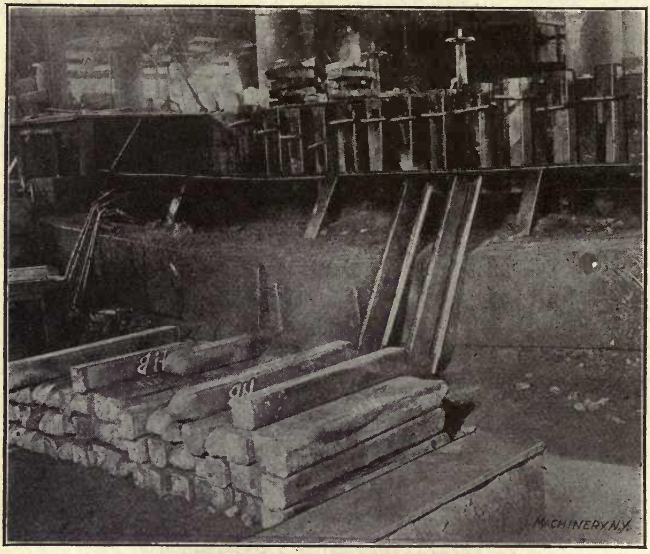

Fig. 5. A Row of Molds ready for the Metal to be poured, an Open Mold, and a Pile of Ingots

heat and the fire-works effect produced is well exhibited in the illustration.

As soon as the metal has been poured, the crucible, which is not permitted to cool off on account of the fact that in such a case it would be destroyed by cracking, is put back into the furnace to be heated up again before recharging. In some cases, when it has not cooled off too much during the pouring, it will be immediately recharged without reheating. When re-heated, however, it is removed from the furnace after a few minutes, and the charge put into it as already described. It is then immediately put back into the furnace where it is permitted to remain from four to six hours when it is again removed, and the metal poured, and the same process repeated. As the furnace is in operation day and night, about five heats are obtained in the course of twenty-four hours. A crucible will only last about four to six heats.

In order to prevent the steel from sticking to the molds, these latter are "smoked" by burning rosin underneath them which leaves a thick black coat of smoke or soot on the face of the mold. The ingots are permitted to cool off in the molds and are then removed and stored in piles on the floor, as shown in Fig. 5.

The Welding Process

The next operation performed is the heating of the ingots in a heating furnace to a welding or white heat, after which they are put through what is termed the welding process. This consists in placing the white hot ingot under the steam hammer and lightly tapping it with gentle

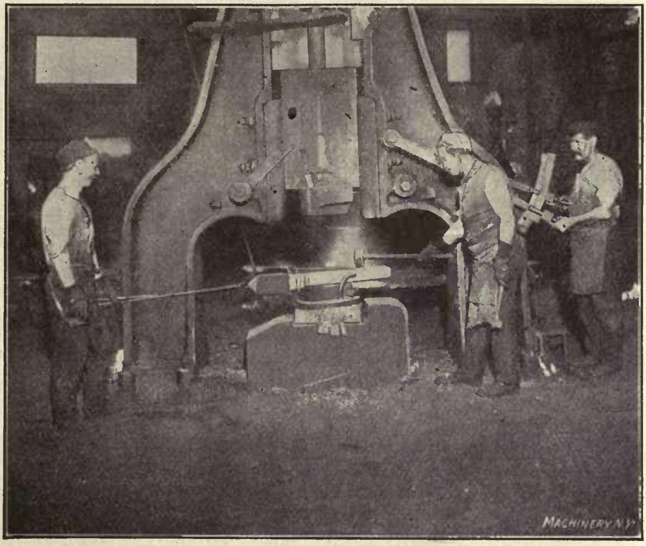

Fig. 6. First Stage in Hammering the Ingot to size under a 2500-pound Bement Hammer

blows on the surface, so as to close up or weld all minute cracks or flaws that may be present on the outside of the ingot. This insures a homogeneous structure and freedom from flaws and cracks in the finished material.

Hammering to Size

After having been welded, the ingot is either again permitted to cool down and it is then re-heated to a red heat, or it may be immediately taken and placed under the steam hammer and hammered down to the required size. In Fig. 6 an ingot is shown where the hammering to size has just commenced. The hammering adds to the firmness and quality of the steel and insures homegeneity of the material. In order to insure the correct size being obtained, tools similar to those employed by regular blacksmiths are used as stops or gages. A square block provided with a long shank, called a peg, of which a number are shown among the tools in Fig. 7, is placed on the anvil of the hammer

and acts as a stop. This block is of the required thickness of the bar. When the steam hammer has hammered down the bar to this size, it will strike this block and is thus prevented from making the bar undersize. Two thin or flat blocks are also shown in Fig. 7, these being used to give the right thickness to the smaller sizes of flat bar stock. After the bar has been thus hammered down to a given size by using the

Fig. 7. A Collection of Tools used when Handling the Ingots and Hammering them to Size

pegs as stops, it is gaged by sheet iron snap gages at various places, in order to ascertain if it has the correct size uniformly along its whole length.

Round bars are made in a similar manner, swages similar to those used by the ordinary blacksmith being employed to obtain a round and smooth surface. In Fig. 8 is shown a smaller steam hammer under which the bars are hammered down to their exact dimensions, this

being in a sense a continuation of the operation of hammering down the ingot, shown in Fig. 6.

When the bars have been thus hammered down to the correct size, it is necessary to anneal them in order that they may be soft enough for working. The bars are therefore placed in an annealing furnace. This furnace contains a number of long large pipes, the ends of some

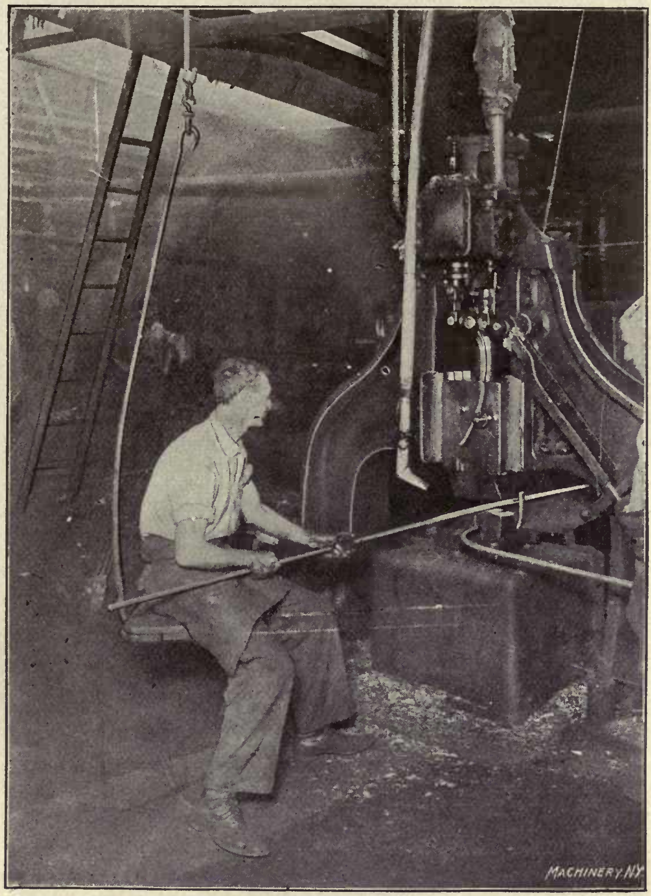

Fig. 8. Hammering a Round Bar to size under a Small Bement Hammer

of which are shown in Fig. 9. They are regular cast-iron water or gas pipes. The bars are placed in these pipes and the ends of the pipes are carefully sealed with fire clay. After this the front of the furnace is closed by the door or cover shown in the illustration, and the furnace is heated for about twenty-four hours; then the fire is deadened and the bars are permitted to slowly cool down for about two days. When taken out of the annealing furnace they are ready for shipment.

The Rolling Mill

All the ingots, however, are not hammered into shape; smaller sizes of square and round stock are rolled to the required size. Two illustrations of the rolling mill are given in Figs. 10 and 11. The ingot is first heated to a high heat and is then placed between the first set of rolls

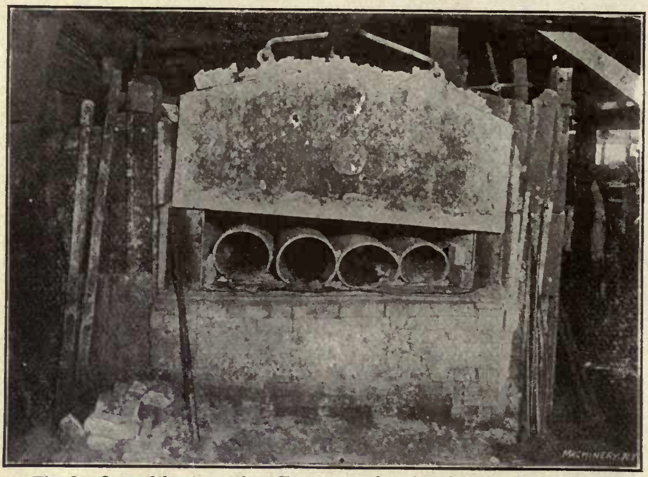

Fig. 9. One of the Annealing Furnaces, showing the Pipes into which the Tool-steel Bars are placed while being heated for annealing

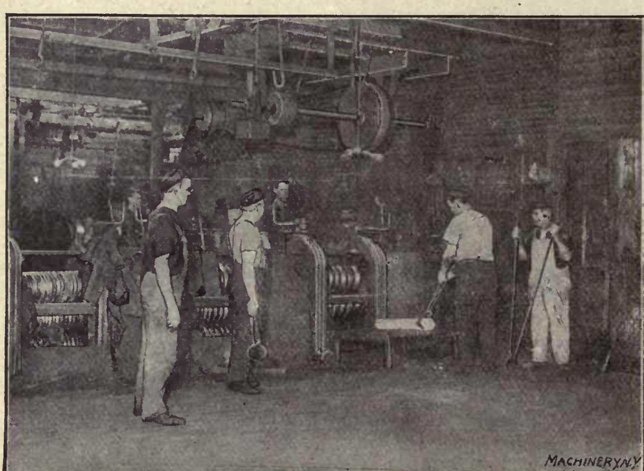

Fig. 10. The Rolling Mill, showing the Ingot just before it passes between the First Set of Rolls

illustrated in Fig. 10, where the ingot is shown ready to pass for the first time between the rolls. It is here passed between the rolls from one side to the other, becoming smaller in cross section and of greater length at each successive pass. It is of interest to note how the

Fig. 11. The Rolling Mill, showing the Ingot after it has been rolled down into a Long Bar of Small Diameter

mechanical operation of rolling keeps the heat in the bar, so that a great number of "passes" can be made without losing any of the original heat; as a matter of fact, the bar shows even a higher degree of heat

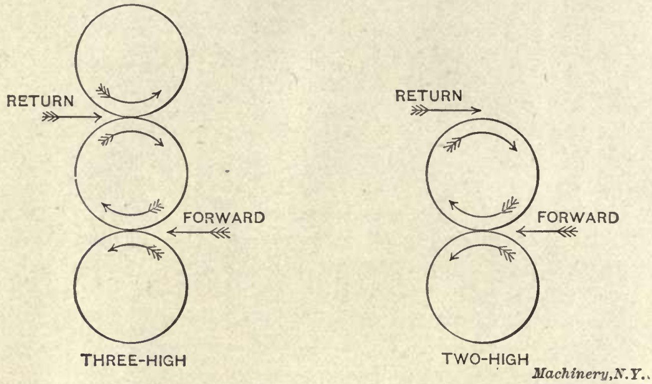

Fig. 12. A Diagrammatical Sketch showing the Difference between the Action of Two- and Three-high Rolling Mills

at successive stages, the work performed on the iron in the rolling process being partly transformed into heat.

In Fig. 11 the ingot is shown rolled down into a long bar of small size. This illustration also shows to the left the heating furnace, and

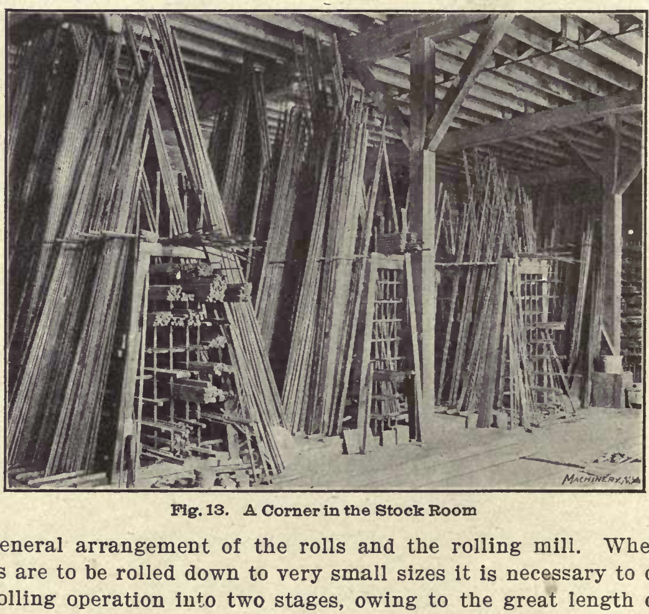

Fig. 13. A Corner in the Stock Room

the general arrangement of the rolls and the rolling mill. When the ingots are to be rolled down to very small sizes it is necessary to divide the rolling operation into two stages, owing to the great length of the bar when it has been rolled down to a comparatively small size. In

such cases the bar, after having first been rolled down to a certain size, is cut up under shears into shorter pieces of equal length, immediately after coming from the rolls. These pieces are re-heated in the furnace and are again passed between the rolls to produce the smaller sizes.

The rolling mill shown in Figs. 10 and 11 is what is called "three-high," that is, it consists of three rolls over each other, of which the bottom and top rolls run in the same direction, while the middle or center roll runs in a direction opposite to both. From the diagrammatical sketch, Fig. 12, it will be seen that by this arrangement it is possible to pass the bar first through the two lower rolls over to one side and then back again through the two upper rolls to the first side. In this way the bar is reduced in size a certain amount each time it passes back and forth. When rolling mills are provided with one set of two rolls only ("two-high") and are not made reversing, as is the case with the set of rolls shown in use in Fig. 11, it is evident that it is possible to pass the bar between the rolls only in one direction, and the bar must be passed back over the top roll to the front side "idle," as is plainly shown in the engraving. When the bar has been rolled down to the required size it is annealed in the same manner as described for the hammered bars, and is then ready for shipment.

In Fig. 13 is shown an illustration of a part of the stock-room, showing the finished bars in the racks.

CHAPTER III

STEEL CASTINGS*

The present chapter consists of an abstract published in the June, 1903, issue of MACHINERY of an article which originally appeared in the journal of the *American Society of Naval Engineers*, February, 1903.

The raw materials that usually enter into the making of steel castings are steel scrap, pig iron and iron ore. The scrap consists of the crop ends of plates, shapes and forgings and the borings and turnings from the machine shop. The bulk of the furnace charge is scrap, the proportion of pig being about one-fifth at the beginning of a run —that is, immediately after a furnace has been rebuilt—and increasing up to nearly three-tenths at the end of the run, when the furnace lining and brick work generally are getting so slagged and burnt out as to require renewal. These proportions are for acid steel, basic steel using larger quantities of pig. The amount of iron in the ore is a secondary consideration, the ore being used chiefly for its oxygen, which comes into play in oxidizing the metalloids, carbon, silicon, sulphur, and phosphorus. The proportions of ore required in a charge depend upon the character of the other ingredients; ordinarily in an acid furnace from one to two, or two and a half per cent would be used. There have been cases where scrap could not be procured, and the charge has been made up, of necessity, entirely of pig and ore, over three-fifths being pig. Hematite ore is the variety most used, and is obtained in large quantities in the Lake Superior region in this country and Canada; much of it is also imported from Cuba, Spain and elsewhere.

The amount of carbon combined with iron makes one difference between wrought iron and steel and between steel and cast iron. A second and equally important difference is the method of manufacture and the resulting properties and character. Wrought iron is soft and fibrous; cast iron is hard, crystalline and brittle; steel comes in anywhere between.

Basic steel is used in making castings, but not so generally as the acid product. Cheaper raw materials can be used in making basic steel, and phosphorus, the element chiefly objected to, can be nearly eliminated. It is more expensive than acid steel, however, and fewer heats per run of furnace can be turned out. With acid steel the number of heats will reach nearly three for each twenty-four hours, depending upon the size of furnace and character and quantity of work.

The raw materials are melted down in a reverberatory furnace with gaseous fuel distilled from special bituminous coals in gas producers. Under each end of the furnace is a pair of regenerators—one for air, one for gas—which communicate with the furnace on one

* MACHINERY, June, 1903.

side and on the other with flues leading to the sources of supply of gas and air to the chimney. Reversing valves are located at the point where the flues meet, and about every twenty minutes, while the furnace is in operation, the valves are shifted and the currents of air and gas turned in the opposite direction. Each regenerator is nearly filled with fire brick built up in such an open checker-board manner that the air and gas find their way among and through them, absorbing heat from them on their way to the hearth, and, when spent, giving up heat to those in the opposite regenerators.

With this type of furnace a temperature of 4000 degrees Fahrenheit can be attained, but as the supply of gas and air is at all times under control, the temperature can be made whatsoever may be desired. The process in the furnace will be acid or basic according to the character of the furnace lining—basic linings and additions being used in one case, and an acid lining, such as ordinary fire brick and fire clay, in the other.

Tests on Steel Castings

Castings requiring annealing are placed in annealing furnaces, where they are gradually and uniformly heated up to temperatures depending upon the composition of the metal and varying between 1200 and 1600 degrees Fahrenheit, kept soaking at the maximum temperature for a time determined by their size, and allowed gradually to cool without exposure to the air. When cold the necessary test specimens are cut from them and machined accurately to the required size. These specimens are then broken or bent in an approved testing machine according to the specifications prescribed. The Bureau of Steam Engineering of the Navy Department prescribes the following regarding the testing of steel castings: Sound test pieces shall be taken in sufficient number to thoroughly exhibit the character of the metal in the entire piece from each of the following castings, *viz.:* Shaft struts or brackets, main cylinder or valve-chest liners, main pistons and followers, eccentric, reversing and rocker shaft arms, crossheads, bedplates, columns of main engines and main air pumps, shaft couplings, and all large castings weighing over 200 pounds. All other castings may be tested by lots, as follows: A lot shall consist of all castings from the same heat, annealed in the same furnace charge. From each lot two or more tensile and one or more bending test pieces shall be taken, and the lot passed or rejected on the results shown by the tests. Large castings shall be suspended and hammered all over with a hammer weighing not less than 7½ pounds. No cracks, flaws, defect or weakness shall appear after such treatment.

The tensile strength of high-class steel castings varies from 65,000 pounds to 80,000 pounds per square inch. The percentage of elongation in two inches varies from 15 to 18 per cent, and the reduction of area from 20 to 25 per cent.

Uses of Steel Castings

Steel castings are used for cylinders and valve-chest covers, for pistons, crosshead guides and slippers, bearing caps and shoes, eccen-

tric sheaves and straps, rocker arms, thrust-bearing boxes and collars, bedplates and housings and other parts of main and auxiliary machinery; for boiler headers, manifolds, drum ends, dry pipes, manhole and handhole doors and other parts of boilers; anchors, anchor davits, hawse pipes, chocks, mooring and towing bitts, stems, stern posts, stern tubes, shaft brackets, manhole covers and other parts of ships' hulls, gun mounts, and parts of dynamos and motors. Their use in ship construction and aboard ship is thus seen to be a large and important matter.

The cast-steel girders for the 16-inch U. S. army gun carriage measure 33 feet by 17 feet by 5 feet, and weigh 100,000 pounds apiece; the carriage presents problems in transportation from the foundry to the arsenal at Watervliet on account of size and weight. A large casting turned out in the eastern part of Pennsylvania for a hydraulic forging press to be set up in the western part of the same State required about 320,000 pounds of metal from six open-hearth furnaces to pour it.

Reliability of Steel Castings

A forged or rolled object is worked down from a billet which previously was hammered or pressed down from an ingot or part of an ingot, and during these stages of manufacture the metal is more or less thoroughly squeezed and pressed and caused to flow upon itself in various directions, and all parts, inside and out, receive some heat and power treatment, so that the impression grows in the minds of those who manipulate the forgings and of those who witness the manipulation that the accepted objects are free from weakening defects; the assurance of their trustworthiness is positive.

In the case of castings no such certainty or confidence is created. A steel casting may come out of the final cleaning process a thing of beauty, the physical and chemical tests may gladden the heart, the required machining may not show any flaws, yet the fear remains that below its surface somewhere a treacherous cavity or other weakness may some day show up—a day when most dependence is necessarily placed upon the casting, when most damage may result from its failure to do its duty.

CHAPTER IV

STEEL HARDENING METALS*

In the 1904 issue of "Mineral Resources of the United States," published by the U. S. Geological Survey, a paper appeared written by Mr. Joseph Hyde Pratt, on Steel-hardening Metals. An abstract of this was published in the May, 1905, issue of MACHINERY.

There are included under the head of steel-hardening metals, nickel and cobalt, chromium, tungsten, molybdenum, vanadium, titanium, and uranium, which are named in the order of the importance of their production and use for steel-hardening purposes.

The special steels resulting from these additions vary among themselves, having individual properties of tensile strength and elastic limit of conductivity for heat and electricity, of magnetic capacity and of resistance to impact, whether as shell or as armor plate. It was only about twenty years ago that the first of these metals, nickel, began to be used to any extent for the purpose of hardening steel, but since their introduction their use for this purpose has continued to increase steadily. Experiments are still being carried on with some of these metals in order to determine their actual commercial value with regard to the qualities that they impart to steel. In the arts it is the ferro-alloy of these various metals that is first prepared and is then introduced in the required quantity into the manufactured steel, but this ferro-alloy is never added to the molten mass during the manufacture of the steel. All these metals give characteristic and distinct properties to steel, but in all cases the principal quality is the increase in the hardness and the toughness of the resulting steel. Some of the metals—as nickel, chromium and tungsten—are now entirely beyond the experimental stage and are well established in the commercial world as definite steel-hardening metals, and new uses are being constantly devised for the different steels, which are causing a constant increase in their production. Others, as molybdenum and vanadium, though they have been proved to given certain positive values to steel, have not been utilized to any large extent as yet in the manufacture of molybdenum or vanadium steel, partly on account of the high cost of the ores containing these metals. Titanium and uranium are still in the experimental stage, and, although a good deal has been written as to the value of titanium as an alloy with steel, there is at the present time very little if any of it used in the manufacture of a commercial steel.

Since the introduction of the electric furnace and the consequent methods that have been devised for reducing ores, it has become possible to obtain these ferro-alloys directly from the ores by reduc-

* MACHINERY, May, 1905.

ing them in the electric furnace, and hence experiments have been conducted on a much larger scale than formerly.

Manganese Steel

Besides the use of ferromanganese for the chemical effect which it produces in the manufacture of steel in eliminating injurious substances, it is also used in the production of a special steel which possesses to a considerable degree combined hardness and toughness. Such steel contains from 0.8 to 1.25 per cent of carbon and about 12 per cent of manganese and is known as "Hadfield manganese steel." If only 1.5 per cent of manganese is added, the steel is very brittle, and the further addition increases this brittleness until the quantity of manganese has reached 4 to 5.5 per cent, when the steel can be pulverized under the hammer. With a further increase, however, of the quantity of manganese, the steel becomes ductile and very hard, reaching its maximum degree of these qualities with 12 per cent of manganese. The ductility of the steel is brought out by sudden cooling, a process the opposite of that used for carbon steel. These properties of manganese steel make it especially adapted for use in the manufacture of rock-crushing machinery, safes, and mine car wheels.

Nickel Steel

Nickel finds its largest use in the manufacture of special nickel and nickel-chromium steels, and the use of these steels for various purposes in the arts is constantly increasing. The greatest quantity of nickel steel is used in the manufacture of armor plate, either with or without the addition of chromium. There is probably no armor or protective deck-plate made which does not contain from 3 up to 5 per cent of nickel. Nickel steel is also used for the manufacture of ammunition hoists, communication tubes, and turrets on battleships, and for gun shields and armor.

The properties of nickel steel or nickel-chromium steel that make it especially adapted for these purposes are its hardness and great tensile strength, combined with great ductility and a very high limit of elasticity. One of the strongest points in favor of a nickel-steel armor plate is that when it is perforated by a projectile it does not crack. The Krupp steel, which represents in composition about the universal armor-plate steel, contains, approximately, 3.5 per cent of nickel, 1.5 per cent of chromium, and 0.25 per cent of carbon.

Another use for nickel-steel that is gradually increasing is the manufacture of nickel-steel rails. During 1903 there were over 11,000 tons of these rails manufactured, which were used by the Pennsylvania, the Baltimore & Ohio, the New York Central, the Bessemer & Lake Erie, the Erie, and the Chesapeake & Ohio railroads. These orders for nickel-steel rails resulted from the comparison of nickel-steel and carbon-steel rails in their resistance to wear during the five months' trial of the nickel-steel rails that were used on the Horseshoe Curve of the Pennsylvania Railroad. The advantages that are claimed for the nickel-steel rails are its increased resistance to

abrasion and its higher elastic limit, which increases the value of the rail as a girder. On sharp curves it has been estimated that a nickel-steel rail will outlast four ordinary rails.

Nickel steel has also been largely adopted for forgings in large engines, particularly marine engines, and it is understood that this is now the standard material for this purpose in the United States Navy. There is now a very great variety of these forgings and drop forgings, including the axles and certain other parts of automobiles, shafting and crank-shafts for government and merchant-marine engines and stationary engines, and locomotive forgings, the last including axles, connecting-rods, piston-rods, crank-pins, link-pins, and pedestal cap bolts.

Another important application that is being tried with nickel-steel is in the manufacture of wire cables, and during the last years such cables have been made by the American Steel and Wire Co., but no comparison can as yet be made between them and the ordinary carbon-steel cables with respect to their wearing qualities.

In the manufacture of electrical apparatus nickel steel is beginning to be used in considerable quantity. The properties of this steel which make it especially valuable for such uses are, first, its high tensile strength and elastic limit, and, second, its high permeability at high inductions. Thus steel containing from 3 to 4 per cent of nickel has a lower permeability at low inductions than a steel without the nickel, but at the higher inductions the permeability is higher. A notable instance of the use of this material is in the field rings of the 5000 H. P. generators built by the Westinghouse Electric and Manufacturing Co. for the Niagara Falls Power Co. These field rings require very high tensile strength and elastic limit, and in order to reduce the quantity it is desirable that they have high permeability at high inductions. This result was secured by using a nickel steel containing approximately 3.75 per cent of nickel. Steel containing approximately 25 per cent of nickel is non-magnetic and has a very low resistance temperature coefficient. This property is occasionally of value where a non-magnetic material of very high tensile strength is required. The high electrical resistance of nickel steel of this quality, together with its low temperature coefficient, makes it valuable for electrical resistance work where a small change in the resistance due to change in temperature is desirable. The main objection to using nickel steel for this purpose is the mechanical defects that are often found in wire that is drawn for this quality of nickel steel.

For rock drills and other rock-working machinery nickel steel is used in the manufacture of the forgings which are subjected to repeated and violent shocks. The nickel content of the steel used in these forgings is approximately 3 per cent, with about 0.40 per cent of carbon. The rock drills or bits are made for the most part of ordinary crucible cast steel which has been hardened and tempered. There is a field for investigation here in respect to the value of some of the special drills in the manufacture of rock-drill steels or bits.

A nickel-chromium steel is now being made which is used to some extent in the manufacture of tools.

Nickel steel in the form of wire has been used quite extensively and for many purposes—for wet mines, torpedo defense netting, electric lamp wire, umbrella wire, corset wire, etc.—where a non-corrosive wire is especially desired. When a low coefficient of expansion is desired—as in the manufacture of armored glass, in the mounting of lenses, mirrors, level tubes, balances for clocks, weighing machines, etc.—nickel steel gives good satisfaction. For special springs, both in the form of wire and flats, a high carbon nickel steel has been introduced to a considerable extent. Nickel steel is also being used in the manufacture of dies and shoes for stamp mills, for cutlery, table ware, harness mountings, etc.

Nickel steels containing from 25 to 30 per cent nickel are used abroad to a considerable extent for boiler and condenser tubes and are now being introduced into this country. The striking characteristic of these steels is their resistance to corrosion either by fresh, salt, or acid waters, by heat, and by superheated steam. The first commercial manufacture of high nickel steel tubes began in France in 1898, and was followed in Germany in 1899; but it was not until February, 1903, that these tubes were made in the United States. Since then, however, Mr. Albert Ladd Colby states:

"The difficulties of their manufacture have been so thoroughly overcome that the 30 per cent nickel-steel, seamless, cold-drawn marine boiler tubes, now a commercial proposition, are made in practically the same number of operations, and with but a slightly greater percentage of discard than customary in the manufacture of ordinary seamless tubes, and, furthermore, the finished 30 per cent nickel-steel tube will stand all the manipulating tests contained in the specifications of the Bureau of Steam Engineering, United States Navy Department, for the acceptance of the carbon-steel seamless cold-drawn marine boiler tubes now in use. In addition, the nickel-steel tubes have a much greater tensile strength."

Although the first cost of the nickel steel tubes for marine boilers is considerably in excess of the carbon-steel tubes, yet, on account of the longer life of the nickel-steel tubes, they are in the end cheaper than the others. At the present time 30 per cent nickel-steel tubes cost from 35 cents to 40 cents per pound, as compared with 12 cents to 15 cents per pound for the corresponding mild carbon-steel tubes. Thus their initial cost, when used in the boilers of torpedo-boat destroyers, is 2.13 times as great as the other kind, and 2.43 times as great when used in the boilers of battleships, but the nickel-steel tubes will last two-and-one-third times longer than those made of the carbon steel, and when finally taken from the boilers they can be sold not only for the market price of steel-tubing scrap, but also at an additional price of 20 cents per pound for their nickel content. Thus it is seen that 30 per cent nickel-steel boiler tubes are really more economical to purchase than carbon-steel boiler tubes.

In addition to marine boilers, high nickel-steel tubes can be used to advantage for stationary boilers, automatic boilers, and locomotive safe ends. It is the higher elastic limit of the 30 per cent nickel-steel boiler tubing that will prevent the leaks that are constantly being formed where the mild carbon-steel tube is used. The leaks are due to the expansion of the flue-sheets when heated, which compress the tubes at the points where they pass through the flue-sheets, and cause in the case of the mild carbon-steel tube a permanent deformation. This results in leakage and necessitates the frequent expanding of the tubes. In the high nickel-steel tubes this difficulty is overcome by their higher elastic limit. This deformation and the resulting leakage are especially true of locomotive boilers. For automobile tubular boilers a 23 to 25 per cent nickel-steel tubing is used, each coiled section being made from one long piece of nickel-steel tubing which, by a special heat treatment, is enabled to withstand this bending without cracking.

Nickel-steel tubing containing 12 per cent of nickel has been used in France since 1898 in the manufacture of axles, brake beams, and carriage transoms for field artillery wagons, and the desired result in the reduction of weight has been obtained without loss of strength and stiffness of the wagons. A 5 per cent nickel-steel tubing has been used in the manufacture of bicycles since 1896.

Chromium Steel

The largest use of chromium is in the manufacture of a ferro-chromium alloy which is used in the manufacture of chrome steel. In the manufacture of armor plate ferro-chrome plays a very important part, and, although it is sometimes used alone for giving toughness and hardness to the armor plate, it is more commonly used in combination with the nickel, making a nickel-chromium-steel armor plate. Other uses of chromium steel are in connection with five-ply welded chromium steel and iron plates for burglar-proof vaults, safes, etc., and for castings that are to be subjected to unusually severe service, such as battery shoes and dies, wearing plates for stone crushers, etc. A higher chromium steel which is free from manganese will resist oxidation and the corrosive action of steam, fire, water, etc., to a considerable extent, and these properties make it valuable in the manufacture of boiler tubes. Chromium steel is also used to some extent as a tool steel, but for high-speed tools it is being largely replaced by tungsten steel, which is especially adapted to this purpose.

The percentage of chromium that is used in the chromium steels varies from 2.5 to about 5 per cent and the carbon from 0.8 to 2 per cent. The hardness, toughness and stiffness which are obtained in chromium steel are very essential qualities, and are what make this steel especially beneficial for the manufacture of armor-piercing projectiles as well as of armor plate. For projectiles, chromium steel has thus far given better satisfaction than any of the other special steels, and is practically the only steel that is used for this purpose. The value of chromium steel for this purpose is well brought out by

Mr. R. A. Hadfield, manager of the Hecla Works, Sheffield, England, who states that a 6-inch armor-piercing shot made by this firm was fired at a 9-inch compound plate, which it perforated unbroken. It was then fired again from the same gun and perforated a second plate of the same thickness, the shot still remaining unbroken.

Tungsten Steel

Tungsten steel is used to some extent more generally abroad than in the United States, in the manufacture of armor plate and armor-piercing projectiles. For this purpose it is used in combination either with nickel or chromium, or with both of these metals. The use, however, for which tungsten steel is best adapted is in the manufacture of high-speed tools and magnet steels. The property that tungsten imparts to the steel is that of hardening in the air after forging and without recourse to the usual methods of tempering, such as immersion in oil, water, or some special solution. For high-speed tools tungsten steel is especially adapted, as it retains its hardness and cutting edge even at the temperature developed in the use of these high-speed tools. The value of tungsten steel for permanent magnets is on account of it retaining comparatively strong magnetism and of the permanence of this magnetism in the steel. This property makes the tungsten steel particularly desirable in instrument work where the calibration of the instrument depends upon the permanence of the magnet used. For compass needles, tungsten steel has been used with entire satisfaction.

Molybdenum

The use of molybdenum steel continues to increase, and hence there is an increasing demand for the ores of this metal. The main use of ferromolybdenum is in the manufacture of tool steel. The properties which molybdenum gives to steel are very similar to those given by tungsten, the main difference being that it requires a smaller quanity of molybdenum than of tungsten to acquire the same results. Ferromolybdenum is produced, like ferrotungsten, by reducing it from the ore in an electric furnace. There are now two molybdenum-nickel alloys being produced, one of which contains 75 per cent molybdenum and 25 per cent nickel, and the other 50 per cent molybdenum and 50 per cent nickel. Besides these constitutents the alloy contains from 2 to 2.5 per cent iron, 1 to 1.5 per cent carbon, and 0.25 to 0.50 per cent silicon. The molybdenum steel which is made from these alloys is recommended for large cranks and propeller-shaft forgings, for large guns, rifle barrels, and for wiring and for boiler plates. The molybdenum increases the elongation of steel very considerably, and for wire drawing such an increase at a comparatively small cost is important.

Vanadium Steel

On account of the extremely high price and scarcity of vanadium ores, the metal has thus far been employed very little in the manufacture of ferrovanadium for use in the production of vanadium steel. It is claimed by many that the beneficial properties imparted to steel

by vanadium exceed those of any of the other steel-hardening metals. These are exaggerated statements, but it may be found that smaller quantities of vanadium will give in some cases the same results that are obtained by comparatively large quantities of the other metals. One property claimed for vanadium steel is that it acquires its maximum of hardness not by sudden cooling, but by annealing at a temperature of from 1300 to 1470 degrees F. This property would be particularly advantageous for high-speed tool steel and for points of projectiles.

Titanium

The actual commercial value of titanium as a steel-hardening metal has not been thoroughly demonstrated. Experiments have shown that from 0.5 to 3 per cent of titanium increases the transverse strength and the tensile strength of steel to a very remarkable degree. Until the development of the electric furnace it was practically impossible to produce either titanium or an alloy of iron and titanium, but since the introduction of this furnace, ferrotitanium can be produced directly from the ores. It is to the manufacture of a special cast iron that ferrotitanium seems to be especially adapted. The titanium in the iron gives greater density to the metal, greatly increases its transverse strength, and gives a harder chill or wearing quality to a wheel made from such an iron. For the manufacture of car wheels it would seem that the titanium iron would be especially useful.

CHAPTER V

DEVELOPMENT AND USE OF HIGH-SPEED STEEL*

The following discussion on high-speed steel and tools made from this material was published in MACHINERY in the December, 1904, issue, and is an abstract of a paper read by Mr. J. M. Gledhill before the Iron and Steel Institute, of Great Britain, October, 1904.

The high-speed steels of the present day are combinations of iron and carbon with: (1) Tungsten and chromium, (2) Molybdenum and chromium, (3) Tungsten, molybdenum and chromium.

Influence of Carbon

A number of tool steels were made by the Armstrong Whitworth Co. with the carbon percentage varying from 0.4 per cent to 2.2 per cent, and the method of hardening was to heat the steel to the highest possible temperature without destroying the cutting edge, and then rapidly cooling in a strong air blast. By this simple method of hardening it was found that the greatest cutting efficiency is obtained where the carbon ranges from 0.4 per cent to 0.9 per cent, and such steels are comparatively tough. Higher percentages are not desirable because great difficulty is experienced in forging the steels, and the tools are inferior. With increasing carbon contents the steel is also very brittle, and has a tendency to break with unequal and intermittent cutting.

Influence of Chromium

Having thus found the best carbon content to range from 0.4 per cent to 0.9 per cent, the next experiments were made to ascertain the influence of chromium varying from 1.0 per cent to 6.0 per cent. Steels containing a low percentage are very tough, and perform excellent work on the softer varieties of steel and cast iron, but when tried on harder materials the results obtained were not so efficient. With an increased content of chromium the nature of the steel becomes much harder, and greater cutting efficiency is obtained on hard materials. It was observed that with an increase of chromium there must be a decrease in carbon to obtain the best results for such a percentage of chromium.

Mention may here be made of an interesting experiment to ascertain what effect would be produced in high-speed steel by substituting vanadium for chromium. The amount of vanadium present was 2.0 per cent. The steel readily forged, worked very tough, and was hardened by heating to a white heat and cooling in an air blast. This tool when tried on medium steel stood well, but not better than the steel with the much cheaper element of chromium in it.

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* MACHINERY, December, 1904.

Influence of Tungsten

This important element is contained in by far the greater number of the present high-speed steels in use. A number of experiments were made with the tungsten content ranging from 9.0 per cent to 27.0 per cent. From 9.0 per cent to 16.0 per cent the nature of the steel becomes very brittle, but at the same time the cutting efficiency is greatly increased, and about 16.0 per cent appeared to be the limit, as no better results were obtained by increasing the tungsten beyond this figure. Between 18.0 per cent and 27.0 per cent it was found that the nature of the steel altered somewhat, and instead of being brittle, it became softer and tougher, and while such tools have the property of cutting very cleanly, they do not stand up so well.

Influence of Molybdenum

The influence of this element at the present time is under investigation, and the experiments with it have so far produced excellent results; it has been found that where a large percentage of tungsten is necessary to make a high-speed steel, a considerably less percentage of molybdenum will suffice. A peculiarity of these molybdenum steels is that in order to obtain the greatest efficiency they do not require such a high temperature in hardening as do the tungsten steels, and if the temperature is increased above 1800 degrees F. the tools are inferior, and the life shortened.

Influence of Tungsten with Molybdenum

It was found that the presence of from 0.5 per cent to 3.0 per cent molybdenum in a high tungsten steel slightly increased the cutting efficiency, but the advantage gained is altogether out of proportion to the cost of the added molybdenum.

Influence of Silicon

A number of high-speed steels were made with silicon content varying from a trace up to 4.0 per cent. Silicon sensibly hardens such steels, and the cutting efficiency on hard materials is increased by additions up to 3.0 per cent. By increasing the silicon above 3.0 per cent, however, the cutting efficiency begins to decline. Various experiments were made with other metals as alloys, but the results obtained were not sufficiently good by comparison with the above to call for comment.

An analysis of one of the best qualities of high-speed steels produced by the author's firm (Armstrong, Whitworth Co.) is as follows: "A.W." Steel.—Carbon, 0.55 per cent; Chromium, 3.5 per cent; Tungsten, 13.5 per cent.

What may be said to determine a high-speed steel, as compared to an ordinary tool steel, is its capability of withstanding the higher temperatures produced by the greatly increased friction between the tool and the work due to the rapid cutting. An ordinary carbon steel containing, say, 1.20 per cent carbon when heated slightly above the critical point and rapidly cooled by quenching in water becomes intensely hard. Such a steel gradually loses this intense hardness as

the temperature of friction reaches, say, 500 degrees F. The lower the temperature is maintained the longer will be the life of the tool, so that the cutting speed is very limited. With rapid cutting steels the temperature of friction may be greatly extended, even up to 1100 degrees F. or 1200 degrees F., and it has been proved by experience that the higher the temperature for hardening is raised above the critical point and then rapidly cooled, the higher will be the temperature of friction that the tool can withstand before sensibly losing its hardness. The high degree of heating (almost to the melting point, in fact) which is necessary for hardening high-speed steel, forms an interesting study in thermal treatment and is indeed a curious paradox, quite inverting all theory and practice previously existing. In the case of hardening ordinary carbon steels very rapid cooling is absolutely necessary, but with high-speed steels the rate of cooling may take a considerably longer period, the intensity of hardness being increased with the quicker rate of cooling.

Heat Treatment of High-speed Steel

Turning now to some points in the heat treatment of high-speed steel, one of the most important is the process of thoroughly annealing it after working into bars. Accurate annealing is of much value in bringing the steel to a state of molecular uniformity, thereby removing internal strains that may have arisen, due to casting and tilting, and at the same time annealing renders the steel sufficiently soft to enable it to be machined into any desired form for turning tools, milling cutters, drills, taps, threading dies, etc. The annealing of high-speed steel is best carried out in muffle furnaces designed for heating by radiation only, a temperature of 1400 degrees F. being maintained from twelve to eighteen hours according to the section of the bars of steel dealt with. Further advantage also results from careful annealing by minimizing risks of cracking when the steel has to be reheated for hardening. In cases of intricately-shaped milling tools having sharp square bottom recesses, fine edges, or delicate projections, and on which unequal expansion and contraction are liable to operate suddenly, annealing has a very beneficial effect toward reducing cracking to a minimum. Increased ductility is also imparted by annealing, and this is especially requisite in tools that have to encounter sudden shocks due to intermittent cutting, such as planing and slotting tools, or others suddenly meeting projections or irregularities on the work operated on.

In preparing high-speed steel ready for use the process may be divided principally into three stages: forging, hardening, and grinding. It is, of course, very desirable that high-speed steel should be capable of attaining its maximum efficiency and yet only require treatment of the simplest kind, so that an ordinarily skilled workman may easily deal with it, otherwise the preparation of tools becomes an expensive and costly matter, and materially reduces the advantages resulting from its use. Fortunately, the treatment of high-speed steel as produced by leading firms is of the simplest; simpler in fact than of

ordinary carbon steels or of the old self-hardening steels. Great care has to be exercised in the heating of the latter steels, for if either are heated above a blood-red heat, say 1600 degrees F., the danger of impairing their efficiency by burning is considerable; whereas with the high-speed steel, heating may be carried to a much higher temperature, even to the melting point, it being practically impossible to injure it by burning. The steel may be raised to a yellow heat for forging, say, 1850 degrees F., at which temperature it is soft and easily worked into any desired form, the forging proceeding until the temperature lowers to a good red heat, say 1500 degrees F., when work on it should cease and the steel be reheated.

In heating a bar of high-speed steel preparatory to forging (which heating is best done in a clear coke fire) it is essential that the bar be heated thoroughly and uniformly, so as to ensure that the heat has penetrated to the center of the bar, for if the bar be not uniformly heated, leaving the center comparatively cold and stiff, while the outside is hot, the steel will not draw or spread out equally, and cracking will probably result. A wise rule in heating is to "hasten slowly."

It is not advisable to break pieces from the bar while cold, the effect of so doing tending to induce fine end cracks to develop which ultimately may extend and give trouble; but the pieces should be cut off while the bar is hot, then be reheated as before and forged to the shape required, after which the tool should be laid in a dry place until cold.

The temperature for hardening high-speed steel varies somewhat according to the class of tool being dealt with. When hardening turning, planing, or slotting tools, and others of similar class, only the point or nose of tool should be gradually raised to a white melting heat, though not necessarily melted; but no harm is done even if the point of the tool becomes to a greater or less extent fused or melted.

The tool should then be immediately placed in an air blast and cooled down, after which it only requires grinding and is then ready for use. Another method, which may be described, of preparing the tools is as follows: Forge the tools as before, and when quite cold grind to shape on a *dry* stone or *dry* emery wheel, an operation which may be done with the tool fixed in a rest and fed against the stone or emery wheel by a screw, no harm resulting from any heat developed at this stage. The tool then requires heating to a white heat, but just short of melting, and afterward complete cooling in the air blast. This method of first roughly grinding to shape also lends itself to cooling the tools in oil, which is specially efficient where the retention of a sharp edge is a desideratum, as in finishing tools, capstans and automatic lathe tools, brass-workers' tools, etc. In hardening where oil cooling is used, the tools should be first raised to a white heat, but without melting, and then cooled down either by air blast or in the open to a bright red heat, say 1700 degrees F., when they should be instantly plunged into a bath of rape or whale oil, or a mixture of both.

Referring to the question of grinding tools, nothing has yet been found so good for high-speed steels as the wet sandstone, and the tools

ground thereon by hand pressure, but where it is desired to use emery wheels it is better to roughly grind the tools to shape on a dry emery wheel or dry stone *before* hardening. By so doing the tools require but little grinding after hardening, and only slight frictional heating occurs, but not sufficient to draw the temper in any way, and thus the cutting efficiency is not impaired. When the tools are ground on a wet emery wheel and undue pressure is applied, the heat generated by the great friction between the tool and the emery wheel causes the steel to become hot, and water playing on the steel while in this heated condition tends to produce cracking.

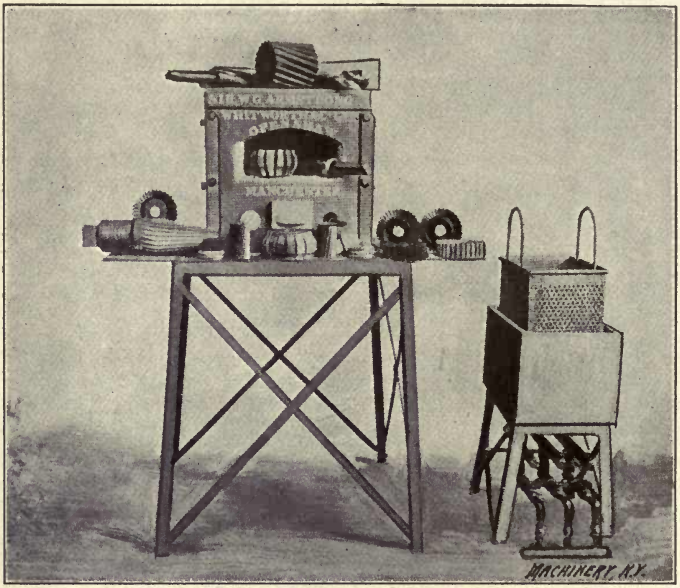

Fig. 14. Muffle Furnace for Hardening Milling Cutters made of High-speed Steel; also Tank and Dipping Cage for Tempering them in Oil

With regard to the hardening and tempering of specially formed tools of high-speed steel, such as milling and gear cutters, twist drills, taps, threading dies, reamers, and other tools that do not permit of being ground to shape after hardening, and where any melting or fusing of the cutting edges must be prevented, the method of hardening is as follows:

A specially arranged muffle furnace heated either by gas or oil is employed, and consists of two chambers lined with fire-clay, the gas and air entering through a series of burners at the back of the furnace, and so under control that a temperature up to 2200 degrees F. may be steadily maintained in the lower chamber, while the upper chamber is kept at a much lower temperature. Before placing the cutters in the furnace it is advisable to fill up the hole and keyways with common fire-clay to protect them. The cutters are first placed upon the top of

the furnace until they are warmed through, after which they are placed in the upper chamber, Fig. 14, and thoroughly and uniformly heated to a temperature of about 1500 degrees F., or, say, a medium red heat, when they are transferred into the lower chamber and allowed to remain therein until the cutter attains the same heat as the furnace itself, *viz.*, about 2200 degrees F. and the cutting edges reach a bright yellow heat, having an appearance of a glazed or greasy surface. The cutter should then be withdrawn while the edges are sharp and uninjured, and revolved before an air blast until the red heat has passed away, and then while the cutter is still warm—that is, *just* permitting of its being handled—it should be plunged into a bath of tallow at about 200 deg. F. and the temperature of the tallow bath then raised to about 520 degrees F., on the attainment of which the cutter should be immediately withdrawn and plunged in cold oil.

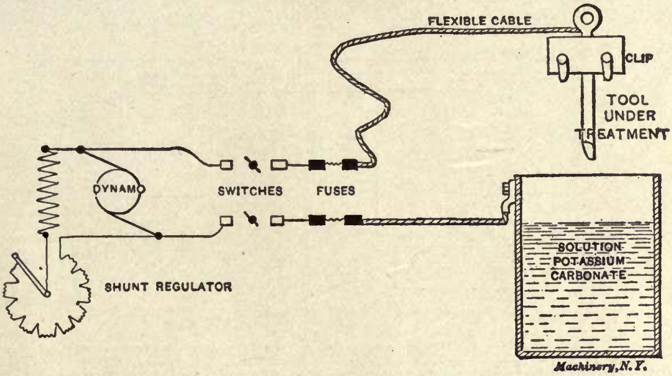

Fig. 15. Apparatus for Hardening Tools Electrically in a Bath of Potassium Carbonate

Of course there are various other ways of tempering, a good method being by means of a specially arranged gas-and-air stove into which the articles to be tempered are placed, and the stove then heated up to a temperature of from 500 degrees F. to 600 degrees F., when the gas is shut off and the furnace with its contents allowed to slowly cool down.

Heating Steel by Electrical Means

Another method of heating tools is by electrical means, by which very regular and rapid heating is obtained, and where electric current is available, the system of electric heating is quick, reliable, and economical. A brief description of this kind of heating may be of interest. One method adopted of electrically heating the points of tools, and the arrangement of apparatus, is shown in Fig. 15. It consists of a cast-iron tank, of suitable dimensions, containing a strong solution of potassium carbonate, together with a dynamo, the positive cable from which is connected to the metal clip holding the tool to be heated, while the negative cable is connected direct on the tank. The tool to be hardened is held in a suitable clip to ensure good contact. Proceeding to harden the tool the action is as follows: The current is

first switched on, and then the tool is gently lowered into the solution to such a depth as is required to harden it. The act of dipping the tool into the alkaline solution completes the electric circuit and at once sets up intense heat on the immersed part. When it is seen that the tool is sufficiently heated the current is instantly switched off, and the solution then serves to rapidly chill and harden the point of the tool, so that no air blast is necessary.

Another method of heating the point of tools is by means of the electric arc, the heating effect of which is also very rapid in its action. The general arrangement and form of the apparatus here employed is as illustrated in Fig. 16. The tool under treatment and the positive electrode are placed on a bed of non-conducting and non-combustible material and the arc started gradually at a low voltage and steadily increased as required, by controlling the shunt rheostat, care being taken not to obtain too great a heat and so fuse the end of the tool.

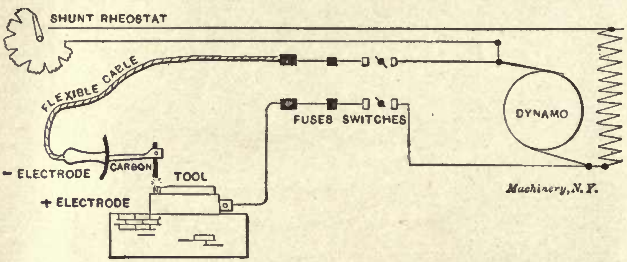

Fig. 16. Apparatus for Heating Tools by the Electric Arc

The source of power in this case is a motor-generator consisting of a continuous-current shunt-wound motor at 220 volts coupled to a continuous-current shunt-wound dynamo at from 50 to 150 volts. Arcs from 10 to 1000 amperes are then easily produced, and simply and safely controlled by means of the shunt rheostat.

Tempering

Electricity is also a very efficient and accurate means of tempering such forms of tools as milling, gear, hobbing and other similar cutters, also large hollow taps, hollow reamers, and all other hollow tools made of high-speed steel, where it is required to have the outside or cutting portion hard, and the interior soft and tenacious, so as to be in the best condition to resist the great stresses put upon the tool by the resistance of the metal being cut, and which stresses tend to cause disruption of the cutter if the hardening extends too deep. By means of the apparatus illustrated in Fig. 17 this tempering or softening of the interior can be perfectly and quickly effected, thus bringing the cutter into the best possible condition to perform rapid and heavy work.

Tempering of hollow cutters, etc., is sometimes carried out by the insertion of a heated rod within the cutter and so drawing the temper, but this is not entirely satisfactory, or scientific, and is liable to induce cracking by too sudden heat application, and further because of the difficulty of maintaining the necessary heat and temperature required,

and afterward gradually lowering the heat until the proper degree of temper has been obtained. In electrical tempering these difficulties are overcome, as the rod is placed inside the cutter quite cold, and the electric current gradually and steadily heats up the rod until the correct temperature is reached. Then it can be held at such temperature as long as is necessary, and the current can be gradually reduced until the articles operated on are cold again, and consequently the risk of cracking by too sudden expansion and contraction is reduced very greatly. The apparatus used is very simple, as will be seen by reference to Fig. 17. It consists of a continuous-current shunt-wound motor directly coupled to a single-phase alternating-current dynamo of the revolving field type giving 100 amperes at 350 volts, 50 cycles per second, the exciting current being taken from the works supply main. The power from the alternator is by means of a stepdown transformer, reduced to current at a pressure of 2 volts, the secondary coil of the

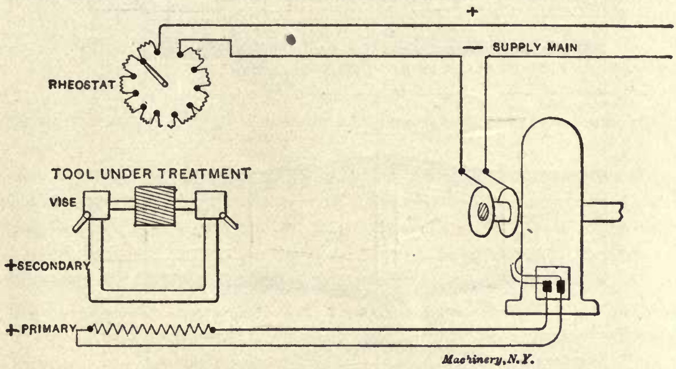

Fig. 17. Apparatus for Tempering Milling Cutters Electrically

transformer consisting of a single turn of copper of heavy cross-section, the extremities of which are attached to heavy copper bars carrying the connecting vises holding the mandrel upon which the cutter to be tempered is placed. The secondary induced current, therefore, passes through a single turn coil, through the copper bars and vises and mandrel. Although the resistance of the complete circuit is very low, still, owing to the comparatively high specific resistance of the iron mandrel, the thermal effect of the current is used up in heating the mandrel, which gradually attains the required temperature, slowly imparting its heat to the tool under treatment until the shade of the oxide on the tool satisfies the operator. The method adopted to regulate the heat of the mandrel is by varying the excitation current of the alternator by means of the rheostat. An extremely fine variation and perfect heat control is easily possible by this arrangement.

Some Results of the Use of High-speed Steel

That great economy is effected by the use of high-speed steel is beyond all doubt, from whichever point of view the question is looked at; for it is not only rapidity of cutting that counts, but the output

of machines is correspondingly increased, so that a greater production is obtained from a given installation than was possible when cutting at low speeds with the old tool steel, and the work is naturally produced at a correspondingly lower cost, and of course, it follows from this that that in laying down new plant and machines the introduction and use of high-speed steel would have considerable influence in reducing expenditure on capital account. It has also been proved that high-speed cutting is economical from a mechanical standpoint and that a given horse-power will remove a greater quantity of metal at a high speed than at a low speed, for although more power is naturally required to

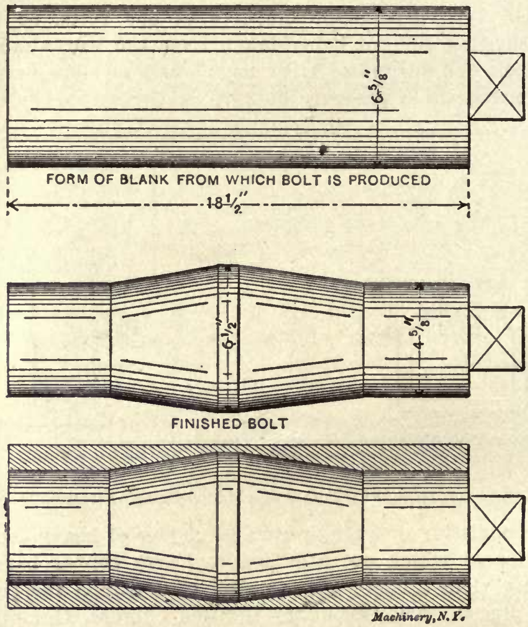

Fig. 18. Armor Bolt Turned at a Cutting Speed of 160 Feet per Minute Feed, 1-32 inch; Mean Depth of Cut, 3-4 inch

take off metal at a high than at a low speed (by reason of the increased work done) the increase of that power is by no means in proportion to the large extra amount of work done by the high-speed cutting, for the frictional and other losses do not increase in anything like the same ratio as a high-cutting speed is to a low-cutting speed. A brief example of this may be given in which the power absorbed in the lathe was accurately measured, electrically.

Cutting on hard steel, with 3/16-inch depth of cut, 1/16-inch feed, and speed of cutting 17 feet per minute, a power of 5.16 horse-power was absorbed, and increasing the cutting speed to 42 feet per minute, the depth of cut and feed being the same, there was a saving in power of 19 per cent for the work being done. Another experiment with depth of cut 3/8 inch and traverse 1/16 inch compared with 1/16 inch traverse

and 3/16 inch depth of cut, showed a saving in power of as much as 28 per cent, and still proceeding with a view of increasing the weight of metal removed in a given time, the feed was doubled (other conditions being the same) and a still further saving of power resulted. In a word, as in the majority of things, so it is with rapid cutting, the more quickly work can be produced the cheaper the cost of production will be.

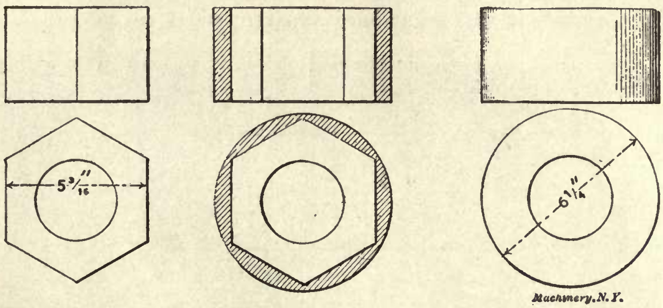

Fig. 19. Examples of Work Milled with a Cutting Speed of 150 Feet per Minute; Maximum Depth of Cut, 1 1-2 inch

Again, as regards economy, there is not only a saving effected on the actual machine work, but since the advent of high-speed cutting it is now possible, in many instances, to produce finished articles from plain rolled bars, instead of following the old practice of first making expensive forgings and afterward finishing them in the machine. By this practice not only is the entire cost of forging abolished, but the machining on the rolled bar can be carried out much quicker and cheaper in

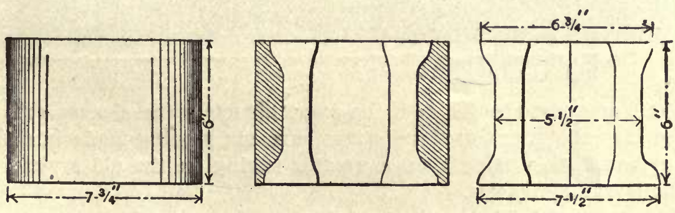

Fig. 20. Sleeves for Armor Bolts Turned with a Cutting Speed of 160 Feet per Minute; Feed, 1-32 inch; Maximum Depth of Cut, 1 1-8 inch

suitably arranged machines, quicker even that the machining of a forging can be done.

A remarkable sample of the gain resulting from the use of high-speed cutting from rolled bars is illustrated in Fig. 18, the articles in this case being securing-bolts, made by the author's firm, for armor plates. Formerly where forgings were first made and then machined with ordinary self-hardening steel, a production of eight bolts per day of ten hours was usual. With the introduction of high-speed steel, forty similar bolts from the rolled bar are now produced in the same time, thus giving an advantage of five to one in favor of quick cutting, and

also in addition abolishing the cost of first rough-forging the bolt to form; in fact, the cost of forging one bolt alone amounted to more than the present cost of producing to required form twelve such bolts by high-speed machining. The cutting speed at which these bolts are turned is 160 feet per minute, the depth of cut and feed being respectively 3/4 inch and 1/32 inch, the weight of metal removed from each bolt being 62 pounds, or 2480 pounds in a day of ten hours, the tool being only ground once during such period of work; from such an example as this it will be at once apparent what an enormous saving

Fig. 21. Making Hexagon Nuts from Rolled Bars with Cutters made from High-speed Steel. Ninety Nuts Produced in a Day of Ten Hours

in plant and cost results. On the same principle the sleeves (see Fig. 20) of these bolts are produced from bars, sixty being made in one day of ten hours, this being even a greater saving on the old system than the bolt example shows.

Equally remarkable results are obtained by operating on stock bars with high-speed milling cutters, and one example among many, may be cited, which is shown in Fig. 19. Here hexagon nuts for 3⅜-inch diameter bolts are made from rolled bars, the cutting speed of milling being 150 feet per minute, giving a production of ninety nuts per day, against thirty formerly. More than ninety nuts could have been produced had the machine been more powerful.

CHAPTER VI

SPARKS AS INDICATIONS OF DIFFERENT KINDS OF STEEL*

The present chapter is an abstract from a paper by Mr. Max Bermann read before the Copenhagen Congress of the International Association for Testing Materials. This abstract was published in MACHINERY, November, 1909. The sparks given off when grinding iron and steel, by means of emery wheels, present a different appearance according to the kind of material ground. In the following, a review is made of the appearance of the sparks of different materials, and explanation is given of the causes of the differences, and the practical applications of this method of steel testing are pointed out.

The path of the spark from its origin to its extinction forms a line of light which may be called the spark-ray. This spark-ray consists of a line of light the end of which branches out in every direction, having an explosion-like appearance. It is this end of the rays that, in particular, varies for different classes of steel, and which in the following will be called the spark-picture. Some of these spark-pictures contain only a very few lines, while others contain a great many, some of them presenting secondary explosions and projections. The rays extending from the drop formation in the spark-picture having a strikingly higher speed than the particles in the spark rays, and it appears as if they were suddenly thrown out in various directions by an internal force.

With a carbon content of from 0.07 to 0.08 per cent, the number of the lines in the spark-picture is from two to three. With an increase of the percentage of carbon the number of the branching lines also increases. At low carbon contents the lines appear to start from different points of the drop formation at the end of the ray, but when the carbon content is as much as 0.25 to 0.27 per cent the lines spring from a common point of the drop formation. The larger the carbon content the greater is the crowding of the lines projecting from the end of the ray. (See Fig. 22.)

The spark-picture of steel containing manganese (see Fig. 23) shows at the end of the individual branching lines a secondary explosion-like phenomenon, shorter lines collecting like leaves around a common central point. The number of the primary branching lines in this case also is in proportion to the carbon percentage in the steel; the extent and shape of the spreading ends of the primary branching lines appear to be in a certain relation to the percentage of manganese contained by the material.

In the case of tool steel, the spark-picture resembles the branch of a blossom, and the individual branching lines have a lilac-like form.

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* MACHINERY, November, 1909.

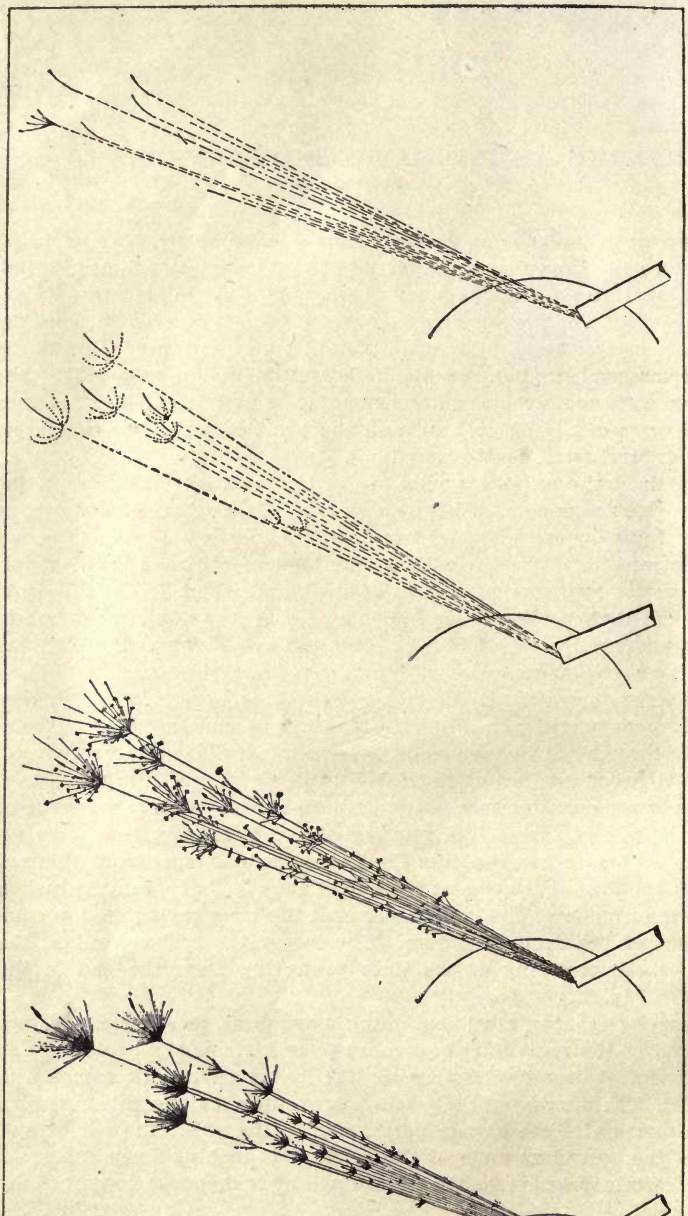

Fig. 22. Spark-picture indicating High-carbon Steel

Fig. 23. Spark-picture of Tool Steel containing Considerable Manganese

Fig. 24. Spark-picture of Steel containing Wolfram

Fig. 25. Spark-picture of Molybdenum High-speed Steel

The spark-rays of steel containing wolfram are dark red lines, the ends of which show no spark-picture if the emery wheel is not sufficiently sharp and the pressure between the wheel and steel is small. Only the very end of the ray has a broader and more brightly glowing appearance, indicating the beginning of a spark picture. If the steel is pressed more firmly against the wheel, branching lines spring out in an explosion-like manner. These lines, however, take the form of small shining pin-head-like balls.

The spark-sheave (the combination of spark-rays and spark-pictures) of chrome-wolfram high-speed steel is distinct from that of the wolfram steel by the fact that two kinds of rays appear, some very thin dark red, and some thicker bright red ones, which are absent in the regular wolfram steel. The spark-pictures consist solely of short curved drop forms.

The spark-picture of nickel steel, containing less than three per cent nickel, is identical with that of carbon steel with a corresponding percentage of carbon. In case of larger percentages of nickel, however, the nickel steel can readily be recognized by the aid of the spark test, because the spark-pictures show themselves in a sporadic manner whereas in the case of carbon steel they occur in close proximity and in close succession to one another.

Dark gray cast iron is characterized by fine dark red spark-rays, spark-pictures here and there, and lines collecting around the drop formation like a net. The net-like lines disappear more and more with the increase of assimilated carbon, and with light gray cast iron they disappear altogether.

Theory of Spark Formations

The spark emitted when grinding is of course a particle of the metal being ground, heated to a high temperature by the friction between the emery wheel and the material. This particle of metal is thrown out in a tangential direction. At a certain point of its line of flight, the red hot spark assumes a red heat; it changes to white heat, and then transforms itself in an explosion-like manner into a spark-picture. At the moment of the explosion-like transformation the spark is in a fluid state. The latter statement can be proved by introducing a plate of glass at right angles to the line of flight, and microscopically examining the glass. It is apparent that the sparks must be in a fluid condition, as they either splash asunder when striking the glass or form crystals of different shapes.

The increase of heat of the spark is caused by an internal source of heat represented, partly, by the combustion heat of the carbon, which suddenly burns. The heat of oxidation of the exterior surface of the mass of sparks prevents too rapid cooling of the spark. The heat of combustion of the carbon provides the quantity of heat necessary for melting the metal. As a matter of fact, however, this heat is not sufficient to melt the whole mass, because the amount of carbon is too small, and only the mass of the unoxidized core within the oxidized iron crust is melted by the quantity of heat available. The combustion gases

of the carbon burst the outer crust of the spark mass and throw out the fluid contents in the direction of the primary branching lines. The silicon and phosphorus contained also burn at the melting heat of the iron, and raise the temperature of the fluid mass. This theory explains why the size of the spark picture increases with the percentage of carbon.

Practical Applications of the Spark Test

The most important practical applications of the spark test may be stated as follows: Different kinds of iron may be classified according to their carbon percentage and the metals principally alloyed with them; ends of rods which may have been wrongly arranged on the storing racks may be placed against the revolving emery wheel and thus identified. It is stated that the spark test is so sensitive that differences of 0.01 per cent of carbon may be perceived. In the inspection of received material the method is valuable for making a rapid test to make sure that the material complies with the requirements. The spark test also supplies a sensitive means of ascertaining differences in chemical composition at different places of the same bar or piece of material, it being possible to apply this test to both steel and cast iron. In the hardening room the spark test may also be of value in order to make sure before hardening what grade and class of steel has been used for making the various tools, so that the proper hardening process may be applied. In the forge shop the method may be of value for determining with certainty good malleable wrought iron.

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